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Operative Techniques in

Sports Medicine

The Glenoid Track and How It Can Guide Management

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The classification and treatment of bone loss in anterior shoulder instability remain as significant challenges to the shoulder surgeon, particularly when bipolar lesions are present. The concept of the glenoid track was developed in order to be able to predict whether engagement of a humeral Hill-Sachs lesion (HSL) would occur in the anterior apprehension position of the shoulder. A rational classification system for HSL as "on-track" (non-engaging) or "off-track" (engaging) flowed out of the biomechanical knowledge of the glenoid track. An "on-track, off-track" treatment paradigm has subsequently been described whereby "off-track" HSL are recommended to be treated by arthroscopic remplissage and Bankart repair to restore shoulder stability and prevent engagement. This article contains a discussion of the history, the biomechanics, and the treatment considerations of Hill-Sachs lesions with a focus on bipolar bone loss as informed by the glenoid track.

KEYWORDS Anterior shoulder instability, bone loss, glenoid track, remplissage

Introduction and Historical Aspects

The importance of bone loss in anterior shoulder instability in the modern era has increasingly been recognized since Burkhart and de Beer's landmark 2000 article demonstrating its association with failed arthroscopic stabilization surgery.[1] Although early authors[2] recognized the humeral head lesion (Fig. 1) as one cause of persistent symptoms or recurrent instability, most experts in the era of open shoulder stabilization either minimized[3] or dismissed[4-6] the importance of bone loss in surgical decision-making. This should not be surprising given the high prevalence (>90%) of chondral and osteochondral Hill-Sachs lesions in first time[7] and recurrent[8,9] anterior instability but historically low rate of their specific treatment in conjunction with open Bankart or capsular shift operations.[10]

Considering the surgical significance of the Hill-Sachs lesion (HSL), Burkhart and de Beer called attention to its "engagement" with the anterior glenoid rim, a phenomenon that could be observed arthroscopically in different positions of the arm.[1] If engagement occurred with the arm in a non-functional athletic position, it was thought to be amenable to isolated arthroscopic Bankart repair (ABR) but if engagement occurred in a functional position, specific treatment of the HSL was recommended.[1] Thus, the emphasis was placed on the *orientation* of the HSL. Other authors have focused on the arthroscopic severity[11] or size[10] (length and depth at open surgery) of the HSL and still others on its radiographic arc length.[12] Despite the high prevalence of HSL and their careful consideration by many authors, no consensus exists as to their classification or treatment.[13]

The Glenoid Track: Definitions

In 2007 Yamamoto et al defined the glenoid track after investigating the contact area between the glenoid and the

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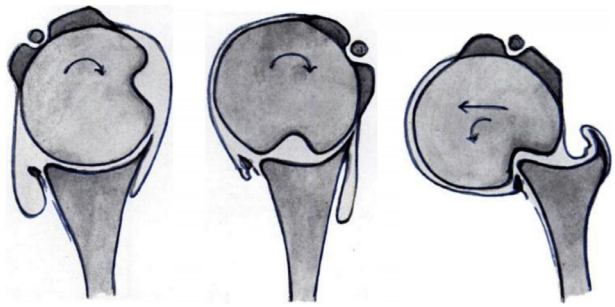

Figure 1 Palmer and Widen[2] recognized that as the arm is externally rotated the "compression cavity" (ie, Hill-Sachs lesion) can engage with the glenoid rim resulting in anterior translation with subluxation. They proposed this as the "essential lesion" in anterior shoulder instability. (Reproduced with permission).

humeral head in the simulated apprehension positions of 0°, 45°, and 90° abduction in full extension and external rotation (Fig. 2A).[14] They defined the "track" as the "zone of contact" between the articular surfaces as the shoulder is moved through the abduction arc in the apprehension position (Fig. 2B). Importantly, Yamamoto calculated the distance between the rotator cuff insertion and medial aspect of the glenoid track (anterior glenoid bony rim) to be 84% ± 14% of the glenoid width (Fig. 3A) in the simulated "90-90" apprehension position. The remaining 16% of the glenoid "pushes out" the posterior rotator cuff. In live subjects using open MRI, Omoroi et al calculated the glenoid track width to be 83% ± 12% of the intact glenoid in a similar arm position.[22]

There are 2 important concepts to the glenoid track. First, in the case of glenoid bone loss, the glenoid track width is decreased (Fig. 3B). Second, if the width of the Hill-Sachs lesion is known (distance from cuff insertion to medial margin), the likelihood of engagement of the HSL with the anterior glenoid can be known by calculating the glenoid track width. Theoretically, if the latter can be calculated preoperatively it can be used to determine treatment *without* the need for arthroscopic assessment.

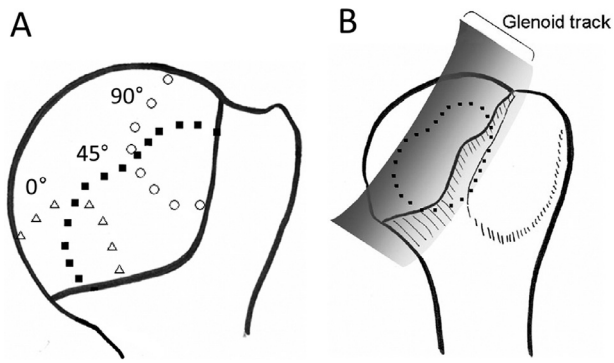

Figure 2 (A) Yamamoto et al marked the outline of the bony glenoid on the humeral head in the simulated 0°, 45°, and 90° abduction positions (A) with the humerus in external rotation and extension.[14] (B) This zone of contact (gray swath) is the "glenoid track." (Reproduced with permission).

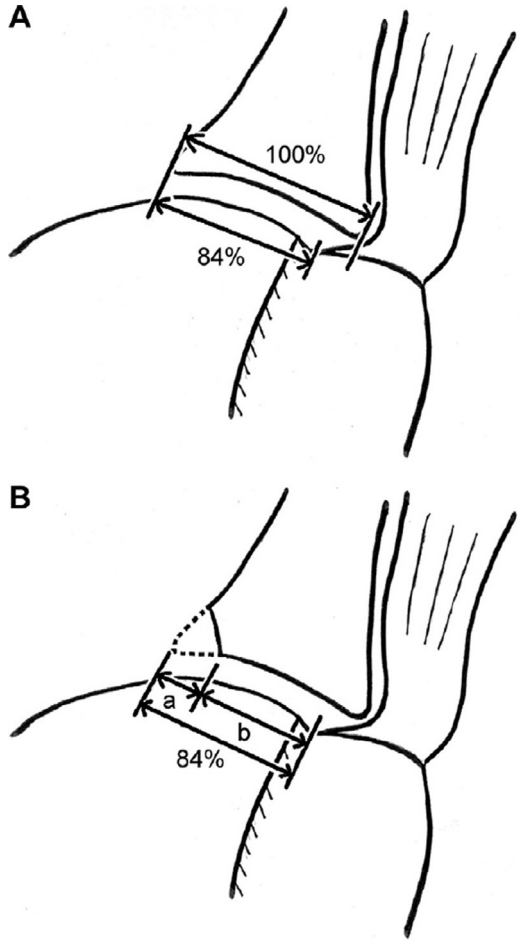

Figure 3 (A) The glenoid track width is 84% of the glenoid width because the posterior rim of the glenoid "pushes out" the rotator cuff–capsular tissue with the arm in the simulated anterior apprehension position. (B) The glenoid track width (b) is shortened by any amount of traumatic glenoid bone loss (a). (Reproduced with permission).

The "On-Track, Off-track" Treatment Paradigm

In 2014, Di Giacomo, Itoi, and Burkhart published a Level V article in which the complementary concepts of the engaging HSL and the glenoid track were reconciled and united.[15] Two problems arise in making treatment decisions about HSL by the arthroscopic assessment of engagement. First, with the anterior capsulolabral tissues torn vs repaired, there is potentially a higher rate of arthroscopic engagement[16] since the absence of the ligamentous constraint at end range is the pathologic condition. Bankart repair would likely lower the rate of the truly engaging HSL.[9] Thus, arthroscopic assessment of engagement with the Bankart lesion unrepaired might result in *overtreatment* of Hill-Sachs lesions.[15] Second, reassessment for engagement after Bankart repair to determine if the HSL is "truly engaging" places the repair at risk for iatrogenic disruption.[15]

In light of these problems, Di Giacomo, et al reasoned that the most rational way to determine the surgical significance

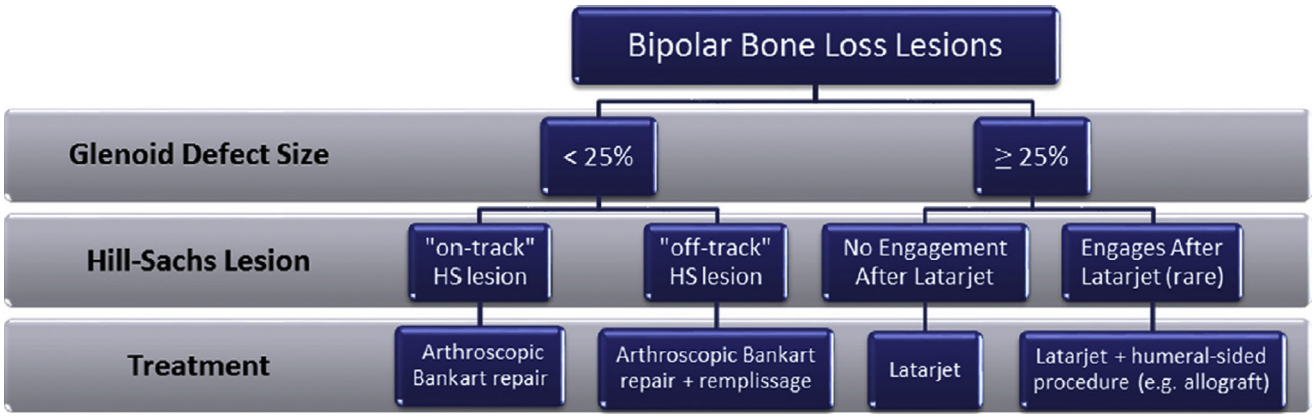

Figure 4 The "on-track, off-track" paradigm for treating traumatic glenohumeral bone loss based on the concept of the glenoid track. Arthroscopic reconstruction is proposed for glenoid bone loss of less than 25%, and remplissage is added to arthroscopic Bankart repair for "off-track" (engaging) Hill-Sachs lesions.[15] (Reproduced with permission).

of a HSL in the setting of potentially significant glenoid bone loss is to use the geometrical considerations allowed by knowledge of the glenoid track. In the proposed treatment paradigm (Fig. 4), open Latarjet is recommended for glenoid bone loss of 25% or more and arthroscopic reconstruction if glenoid bone loss is less than 25%. ABR is recommended if a HSL is "on-track" and ABR plus arthroscopic Hill-Sachs remplissage (ABR + R) is recommended if a HSL if "off-track." Once glenoid bone loss is determined, the glenoid track is calculated as 83% of the intact glenoid minus any glenoid bone loss (Figs. 3 and 5). Next, the Hill-Sachs interval (HSI, the distance from the rotator cuff attachment to the medial edge of the HSL) is determined. Finally, the lesion is classified as "on-track or "off-track." If the HSI is smaller than the glenoid track the lesion is considered "on-track." If the HSI is larger than the glenoid track the lesion is considered "off-track" (Fig. 5). The 5 steps are summarized as follows (Figure 6):

1. Determine the intact glenoid diameter/width (D)
2. Determine the amount of bone loss (d).
3. Calculate the glenoid track (GT) as: (0.83D) − d.
4. Measure the HSI.
5. Determine if the lesion is on or off track as follows: HSI > GT = off-track or HSI < GT = on−track.

In essence, a HSL calculated to be "off-track" means that it is predicted to be "engaging" after Bankart repair with the arm in the functional position of apprehension.

One point of ambiguity in the description of the "on-track, off-track" treatment paradigm is the source of the bony measurements. Both radiographic and intraoperative arthroscopic measurements are allowed. The topic of bone loss assessment in shoulder instability is covered in detail in a companion article in this issue[31] and a detailed discussion on this topic is beyond the scope of this article. However, it is important to note that radiographic and intraoperative methods (Fig. 6) often result in different bone loss measurements.[17] Our recommendation is that radiographic calculations should always be performed for preoperative planning and counseling of the patient. If the intraoperative measurements are used for the final decision on reconstruction, the surgeon should be aware that bone loss is often overestimated by this method, particularly when the glenoid bare spot is used to determine the geometric center of the inferior glenoid.[18]

Biomechanics of "On-Track and Off-Track" Lesions

The authors validated the "on-track, off-track" paradigm from the biomechanical standpoint using a "moderate" 15% glenoid bone loss model with double-pulley remplissage[19] of on-track (15% humeral arc-length) and off-track (30% arc-length) Hill-Sachs lesions.[20] In this model, an on-track HSL rarely engaged with the anterior glenoid rim in the apprehension position and engagement could be prevented by Bankart repair only, thus confirming the previous findings of Elkinson et al.[21] The off-track HSL routinely engaged the glenoid rim, and engagement could not reliably be prevented without the addition of remplissage. In this model, remplissage resolved the engagement problem for both on- and off-track HSL at the cost of supraphysiologic joint stiffness and restriction of external rotation, particularly for the scenario of the large (30%) HSL.

Limitations of the Glenoid Track and "On-Track, Off-Track Paradigm"

Both the glenoid track concept itself and the "On-Track, Off-Track" treatment paradigm have limitations that should be kept in mind as these are used to guide management in treating shoulder instability, particularly in surgical decision making.

First, as has been discussed, the glenoid track width is less than 100% of the glenoid width because the posterior glenoid "pushes out" against the posterior rotator cuff-capsular insertion (Fig. 3). Both Yamamoto[14] and Omori[22] report fairly large standard deviations around the mean 83%-84% (±14% and

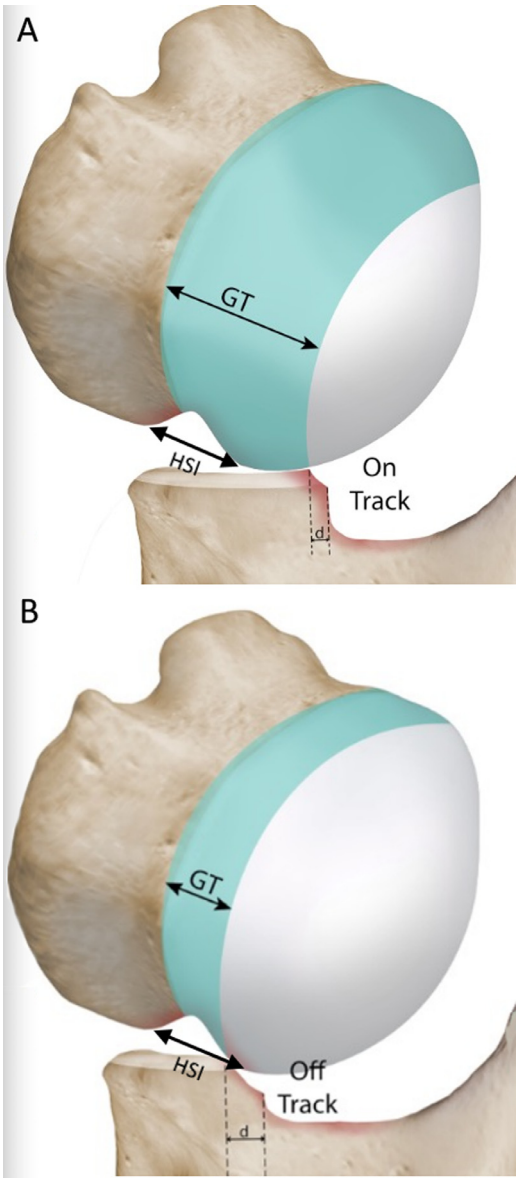

Figure 5 (A) An on-track (non-engaging) Hill-Sachs lesion has the glenoid track (GT) width larger than the Hill-Sachs interval (HSI). (B) Since glenoid bone loss (d) is larger in the off-track scenario, the GT width is now smaller than the HSI allowing engagement.

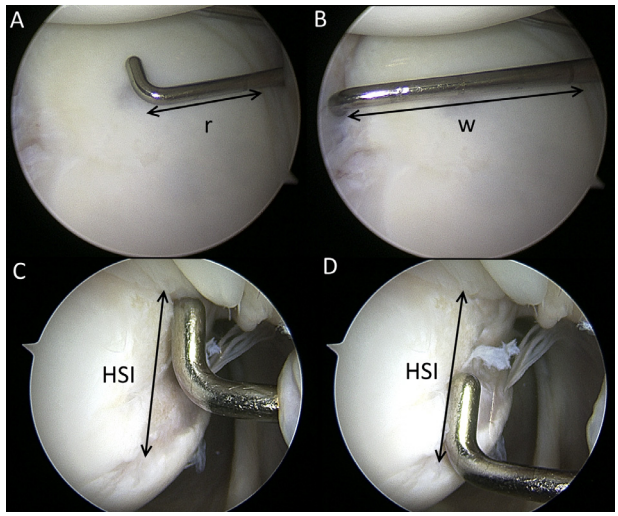

Figure 6 The on- or off-track status of a right shoulder Hill-Sachs lesion as calculated by the glenoid track (GT) method using intraoperative bone loss measurements (anterosuperior view). (A) The posterior radius (r) of the inferior glenoid is measured from the bare area. The intact diameter, D, is calculated as 2r. (B) The width of the inferior glenoid (w) is measured. If bone loss is present, it is calculated by $d = 2r - w$. The GT is calculated as $0.83 * D - d$. The Hill-Sachs interval (HSI) is measured by sequential placement of the probe tip (C) and (D) from the posterior portal. If HSI > GT, the HSL is off−track.

±12%, respectively) width of the glenoid that is to calculate the glenoid track width. One can infer from these statistics that the glenoid track width varies substantially and depends on the tissue properties of the individual patient. Second, the glenoid track has been calculated based on normal and fully intact anteroinferior capsulolabral tissues. In the pathologic state, the anterior tissues will have been surgically repaired and may have been mechanically compromised (ie, stretched out). Third, the glenoid's track on the humeral head has been calculated under highly specific conditions (ie, the maximum external rotation and extension positions caused by arbitrarily torques), about 60° external rotation and 20° extension. Certain patients, particularly overhead athletes, might eventually attempt to return to activities that place the shoulder in even higher degrees of external rotation, extension, and abduction than what was tested in these experiments, thereby functionally decreasing the glenoid track widths in these cases. Fourth, since the anatomy of capsule vs labrum was hidden from the experimenters, the glenoid track was calculated based on the bony anatomy of the anterior glenoid. It may be that the functional glenoid track width actually includes the width of labrum (ie, the labrum is protective of engagement). Last, the glenoid track concept doesn't account for the depth of the HSL. It may be that HSL are only symptomatic at a certain depth, particularly in regard to creating recurrent
instability by engagement.

The "on-track, off-track" treatment paradigm (Fig. 4) has related limitations. First, as Di Giacomo et al note, the judgment of the surgeon regarding individual patient factors should not be neglected.[15] In considering the treatment of a significant HSL, a remplissage might be too restrictive in a throwing athlete, insufficient treatment for a contact athlete with an off-track lesion, or necessary treatment for a contact athlete with an on-track lesion. The paradigm does not consider the quality of the capsulolabral tissues, which might be compromised in the recurrent dislocator or in the revision setting. Furthermore, the surgeon will always be confronted with "borderline" cases (eg, the Hill-Sachs interval is 0-1 mm less than the calculated glenoid track). Even in the biomechanical sense, it is unclear as to what "buffer zone" might exist for engagement as the HSI nears the size of the GT.[20,23] In these cases, several other factors, as above, will need to be considered in making the final treatment decision.

Second, one of the premises of the "on-track, off-track" paradigm is that conversion by remplissage of an off-track to an on-track lesion is a superior treatment modality to Latarjet (or other bony reconstructive options such as iliac crest or distal tibia

allograft) or other open surgical options (eg, capsular shift, allograft reconstruction). This premise is attractive but unproven. In the era of arthroscopy, remplissage is a minimally invasive yet nonanatomic operation. Remplissage has good clinical and biomechanical support[24]; however, certain studies suggest a higher recurrence rate[25] in high risk patients or inferior patient outcomes[26] (eg, pain, external rotation) with ABR + R. Furthermore, there is likely a clinical limit to the size of a HSL that can be safely treated by remplissage without over constraining the shoulder.[13,20] It is important to note that in biomechanical evaluation, remplissage produces supraphysiologic stiffness and the consequence of that over the long term is not unknown. Although retrospective study has suggested the glenoid track concept is highly predictive of recurrence (and possibly more predictive that glenoid bone loss alone),[23,27] no clinical data exist as to the prospective use of the "on-track, off-track" treatment paradigm. Furthermore, it will be many years until long enough follow-up has been obtained to understand the effect of the paradigm on the true recurrence rate.

Third, the surgeon is directed toward arthroscopic surgery or Latarjet based solely upon the amount of glenoid bone loss (25%). While 25% (or even 20%) bone loss has excellent clinical and biomechanical data in support as a cutoff for Bankart-style soft tissue repair (anterior capsulolabral repair or capsulorrhaphy), recent evidence points to a lower threshold (so-called "subcritical" glenoid bone loss) of as low as 13% where both recurrence and functional outcomes deteriorate with arthroscopic Bankart repair.[28] Should it be found that subcritical bone loss requires treatment with a bony procedure, the "on-track, off-track" paradigm might be supplanted, since Latarjet will adequately treat the vast majority of HSL,[15] as might other glenoid reconstructive options.[29,30] Last, if subcritical glenoid bone loss exists and no HSL is present in which to perform remplissage, the surgeon must choose in the paradigm between isolated ABR and Latarjet.

Conclusions

The glenoid track concept and the "on-track, off-track" treatment paradigm represent an advancement in understanding the pathomechanics of anterior shoulder instability and hold great potential for guiding treatment. Specifically, these concepts allow the surgeon a potential analytical method to predict whether a Hill-Sachs lesion will engage with the anterior glenoid rim in the apprehension position (90° abduction in maximum extension and external rotation) *after* an anatomic arthroscopic Bankart has been performed, even in the setting of bipolar bone lesions. Ideally, a rational treatment paradigm would *prevent overtreatment* (ie, unnecessary nonanatomic reconstruction by remplissage or Latarjet) of traumatic bone lesions and but also *prevent undertreatment* (ie, an unacceptably high recurrence rate or poor functional outcomes due to engagement or apprehension). Conceptually, the glenoid track and the "on-track, off-track" paradigm are extremely attractive in providing a rationale for HSL classification and treatment; however, they have significant disadvantages, including lack of clinical follow-up, specificity about other HSL characteristics, and the limitations of remplissage for treating large HSL. The glenoid track concept is not a panacea for decision−making in shoulder instability but does provide an important source of additional information for the surgeon.

References

1. Burkhart SS, De Beer JF: Traumatic glenohumeral bone defects and their relationship to failure of arthroscopic Bankart repairs: Significance of the inverted-pear glenoid and the humeral engaging Hill-Sachs lesion. Arthroscopy 16:677-694, 2000
2. Palmer I, Widen A: The bone block method for recurrent dislocation of the shoulder joint. J Bone Joint Surg Br 30B:53-58, 1948
3. Rowe CR, Patel D, Southmayd WW: The Bankart procedure: A long-term end-result study. J Bone Joint Surg Am 60:1-16, 1978
4. Pollock RG, Bigliani LU: Glenohumeral instability: Evaluation and treatment. J Am Acad Orthop Surg 1:24-32, 1993
5. Thomas SC, Matsen FA: An approach to the repair of avulsion of the glenohumeral ligaments in the management of traumatic anterior glenohumeral instability. J Bone Joint Surg Am 71:506-513, 1989
6. Wirth MA, Blatter G, Rockwood CA: The capsular imbrication procedure for recurrent anterior instability of the shoulder. J Bone Joint Surg Am 78:246-259, 1996
7. Taylor DC, Arciero RA: Pathologic changes associated with shoulder dislocations. Arthroscopic and physical examination findings in first-time, traumatic anterior dislocations. Am J Sports Med 25:306-311, 1997
8. Yiannakopoulos CK, Mataragas E, Antonogiannakis E: A comparison of the spectrum of intra-articular lesions in acute and chronic anterior shoulder instability. Arthroscopy 23:985-990, 2007
9. Kurokawa D, Yamamoto N, Nagamoto H, et al: The prevalence of a large Hill-Sachs lesion that needs to be treated. J Shoulder Elbow Surg 22:1285-1289, 2013
10. Rowe CR, Zarins B, Ciullo JV: Recurrent anterior dislocation of the shoulder after surgical repair. Apparent causes of failure and treatment. J Bone Joint Surg Am 66:159-168, 1984
11. Calandra JJ, Baker CL, Uribe J: The incidence of Hill-Sachs lesions in initial anterior shoulder dislocations. Arthroscopy 5:254-257, 1989
12. Richards RD, Sartoris DJ, Pathria MN, Resnick D: Hill-Sachs lesion and normal humeral groove: MR imaging features allowing their differentiation. Radiology 190:665-668, 1994
13. Provencher MT, Frank RM, Leclere LE, et al: The Hill-Sachs lesion: Diagnosis, classification, and management. J Am Acad Orthop Surg 20:242-252, 2012
14. Yamamoto N, Itoi E, Abe H, et al: Contact between the glenoid and the humeral head in abduction, external rotation, and horizontal extension: A new concept of glenoid track. J Shoulder Elbow Surg 16:649-656, 2007
15. Di Giacomo G, Itoi E, Burkhart SS: Evolving concept of bipolar bone loss and the Hill-Sachs lesion: From "engaging/non-engaging" lesion to "on-track/off-track" lesion. Arthroscopy 30:90-98, 2014
16. Cho SH, Cho NS, Rhee YG: Preoperative analysis of the Hill-Sachs lesion in anterior shoulder instability: How to predict engagement of the lesion. Am J Sports Med 39:2389-2395, 2011
17. Funakoshi T, Hartzler R, Stewien E, Burkhart S: Bipolar bone loss measurements in shoulder instability: Poor agreement between 3D CT and arthroscopic values. Arthroscopy 34(12):e30, 2018
18. Shin SJ, Jun BJ, Koh YW, McGarry MH, Lee TQ: Estimation of anterior glenoid bone loss area using the ratio of bone defect length to the distance from posterior glenoid rim to the centre of the glenoid. Knee Surg Sports Traumatol Arthrosc 26:48-55, 2018
19. Koo SS, Burkhart SS, Ochoa E: Arthroscopic double-pulley remplissage technique for engaging Hill-Sachs lesions in anterior shoulder instability repairs. Arthroscopy 25:1343-1348, 2009
20. Hartzler RU, Bui CN, Jeong WK, et al: Remplissage of an off-track Hill-Sachs lesion is necessary to restore biomechanical glenohumeral joint stability in a bipolar bone loss model. Arthroscopy 32:2466-2476, 2016

21. Elkinson I, Giles JW, Faber KJ, et al: The effect of the remplissage procedure on shoulder stability and range of motion: An in vitro biomechanical assessment. J Bone Joint Surg Am 94:1003-1012, 2012
22. Omori Y, Yamamoto N, Koishi H, et al: Measurement of the glenoid track in vivo as investigated by 3-dimensional motion analysis using open MRI. Am J Sports Med 42:1290-1295, 2014
23. Yang T-C, Chen K-H, Chiang E-R, Chang M-C, Ma H-L: Using the "Hill-−Sachs interval to glenoid track width ratio" for prediction of recurrent instability after arthroscopic Bankart repair. Orthop Traumatol 2018
24. Liu JN, Gowd AK, Garcia GH, Cvetanovich GL, Cabarcas BC, Verma NN: Recurrence rate of instability after remplissage for treatment of traumatic anterior shoulder instability: A systematic review in treatment of subcritical glenoid bone loss. Arthroscopy 34:2894-2907, 2018. e2892
25. Yang JS, Mazzocca AD, Arciero RA: Remplissage versus modified latarjet for off-track Hill-Sachs lesions with subcritical glenoid bone loss. Orthop J Sports Med 5(7_suppl6), 2017. 2325967117S2325900274
26. Bah A, Lateur GM, Kouevidjin BT, et al: Chronic anterior shoulder instability with significant Hill-Sachs lesion: Arthroscopic Bankart with remplissage versus open latarjet procedure. Orthop Traumatol Surg Res 104:17-22, 2018
27. Cook CJB MD, Shaha CJS MD, Rowles CDJ MD, Bottoni CRCR MD, Shaha SHP, Tokish CJM MD: Clinical Validation of the "On-Track" Vs. "Off-Track" Concept in Anterior Glenohumeral Instability. Scottsdale, AZ: Society of Military Orthopaedic Surgeons, 2014
28. Shaha JS, Cook JB, Song DJ, et al: Redefining "critical" bone loss in shoulder instability: Functional outcomes worsen with "subcritical" bone loss. Am J Sports Med 43:1719-1725, 2015
29. Wong IH, King JP, Boyd G, Mitchell M, Coady C: Radiographic analysis of glenoid size and shape after arthroscopic coracoid autograft versus distal tibial allograft in the treatment of anterior shoulder instability. Am J Sports Med 46:2717-2724, 2018
30. Wong IH, Urquhart N: Arthroscopic anatomic glenoid reconstruction without subscapularis split. Arthrosc Tech 4:e449-e456, 2015
31. Provencher MT, Peebles LA, Decker TJ, et al: Assessment of bone loss in the shoulder. Op Tech Sports Med 27, 2019. XXX-XXX (UPDATE THIS REFERENCE THIS IS BEING PUBLISHED IN THIS ISSUE)